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Optimisation of electric distribution systems: A review

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ABSTRACT

Distribution system optimisation is defined as satisfying the demand of the system in the most economical, reliable and environment-friendly way while all the related operational or geographical constraints are met. In the case that the future load of the system is intended to be met, the problem is also called "expansion planning" problem. In this paper, the existing researches on distribution system optimisation problem are reviewed from the viewpoint of their used optimisation algorithm, used objectives, used decision variables, load model, case study, planning type and planning period. This review found that although diverse optimisation algorithms have already been applied to distribution system optimisation problem, developing efficient algorithms with the ability of escaping from local optima and finding near-global solutions is required. In particular, development of diversity enhancement strategies for metaheuristics and applying them to this problem seems to be fruitful. This review also found that some aspects of distribution systems such as deregulation and demand side management have not been taken into account in modelling of distribution system optimisation problem.

Contents

1. Introduction

The electric power system has three main components; generation, transmission and distribution. Among these three components, the distribution system is the most critical and important component in terms of its impact on reliability and quality of supplied electricity and also cost of electricity [1–4]. Distribution systems are the main source of power losses in the power system and also the main cause of service interruptions [1]. Because of the extensive infrastructure, distribution systems are considered as very capital-intensive businesses [1]. Distribution systems are mostly radial meaning that there is no loop in their single line diagram [5–7]. Radial circuits have advantages over meshed systems [1]. Easier protection, lower fault currents, lower cost, easier voltage and power flow control are the main advantages of radial distribution systems over meshed distribution systems [1].

To increase reliability of distribution systems, radial circuits have normally open tie switches for potential connection with other circuits. If a fault happens on one of the circuits, the tie switches allow some portion of the faulted part to be restored promptly; however, the circuits still operate radially. Moreover, there are some normally close sectionalising switches throughout the distribution system that their statuses may be changed as the need arises [1]. A very important point about distribution systems is that their best performance should be achieved [8–21]. This represents "distribution system optimisation" problem. Distribution system optimisation (DSO) can be defined as satisfying the demand of the system in the most economical, reliable and environment-friendly way while all the related operational or geographical constraints are met. In the case that the future load of the system is intended to be satisfied, the problem is also called

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"expansion planning" problem. Therefore, in this paper, distribution system optimisation refers to both distribution system expansion planning and optimisation of current distribution system. The constraints that should be satisfied in distribution system optimisation problem are as follows:

- Connectivity of the system should be maintained, meaning that all load nodes should be supplied.
- The radiality of the system should be maintained.
- The voltages of nodes should be confined in a specified range.
- The current of branches should not violate their corresponding limits.

For optimisation of distribution systems, the statuses of tie and sectionalising switches may be changed, new substations may be built, the conductors may be upgraded and automatic reclosers, capacitors or distributed generation (DG) units may be installed. In the case that the capacitors or DG units are going to be installed in distribution systems, their optimal number, size and location should be determined. The possible objectives in distribution system optimisation problem are minimisation of operational and investment costs, minimisation of copper losses, enhancement of reliability metrics and minimisation of environmental effects.

In this paper, a large number of existing research works on distribution system optimisation problem will be investigated from different perspectives. Actually, they will be investigated from viewpoint of used optimisation algorithm, used objective(s), used decision vectors (the control variables of optimisation process), load model, case study, planning type and period (if any). It should be mentioned here that in case of distribution system expansion planning problem, there exist different planning types. In the first type, named as single stage planning, the planning is merely done for one planning stage (one time). In the second type, named as "stage by stage planning", the planning is conducted for multiple stages while the stages are planned one after the other. In the third planning type, named as "simultaneous multistage planning", all the stages are considered simultaneously. In this strategy, the cost of each stage is not optimum whereas the total cost of the whole planning period is optimum.

Due to the following reasons, conducting this research is necessary and useful:

- Distribution system optimisation is a very crucial problem in electrical engineering. It is very useful to review different existing research works on distribution system optimisation problem and identify the research gaps so that the gaps are addressed in the future research works.
- The diverse set of optimisation algorithms, applied to distribution system optimisation problem has not been reviewed previously. Proper review of the existing used algorithms may lead to guidelines for design of new optimisation paradigms for this problem.

To date, few reviews on distribution system optimisation have been published. In 1983, a review on distribution system expansion models has been provided [22]. However, it does not analyse different optimisation schemes applied to this problem. Moreover, now, it is considered an outdated work since it has been done more than two decades ago. In [23], a review on models and methods used in distribution system planning has been provided. Although [23] is of very high quality and value, the following three features distinguish this work from [23].

- Unlike [23], which analyses a limited number of optimisation schemes applied to distribution system planning problem, this work analyses very diverse set of optimisation algorithms such as teaching–learning based optimisation, big bang-big crunch optimisation algorithm, fireworks optimisation algorithm, group search optimisation, seeker optimisation, imperialistic competitive algorithm, cuckoo search optimisation algorithm and firefly swarm optimisation algorithms applied to distribution system optimisation problem.
- Unlike [23], in this review, the proposed strategies for avoiding premature convergence in optimisation algorithms are reviewed. Such strategies try to establish more appropriate trade-off between explorative and exploitative capabilities so that the algorithm converges into global optimum instead of the local ones.
- Unlike [23], which only provides a review for distribution expansion planning problem (the optimisation of distribution system performance for future load levels), this paper provides a review on distribution system optimisation problem which includes optimisation of both current system and future system.

This paper is organised as follows; in Section 2, the existing research works are reviewed from viewpoint of their optimisation algorithms, objectives and decision vectors. In Section 3, the research works are reviewed from viewpoint of planning period, planning type and load model. In Section 4, an overall review of existing research works on distribution system optimisation has been provided and some directions for future research are presented. Eventually, the conclusions are drawn in Section 5.

2. Review from viewpoint of used optimisation algorithms, objectives and decision vectors

In this section, the existing research works on distribution system optimisation problem are reviewed from the viewpoint of their used optimisation algorithms, objectives and decision vectors, although the main focus of this paper is on reviewing optimisation algorithms applied to distribution system optimisation problem. The statuses of sectionalising and tie switches, conductor types, size and location of new substations, number, size and location of capacitors and DG units are the common decision variables of distribution system optimisation problem. The possible objectives in this problem are minimisation of operational and investment costs, minimisation of copper losses, enhancement of reliability metrics and minimisation of environmental effects. From optimisation perspective, distribution system optimisation problem is considered as a highly constrained, high-dimension, mixed integer, nonlinear, multi-modal optimisation problem with large number of local optima. Finding near global solutions in such a complex optimisation problem is very formidable and demanding. For solving this complex optimisation problem, there are three categories of approaches; classic approaches, metaheuristic approaches and technical approaches. Classic approaches include deterministic algorithms such as linear programming, nonlinear programming and dynamic programming. Generally, these approaches are not efficient enough in solving distribution system optimisation problem and there exist few cases of their application on this problem [24–26]. The second category of approaches are based on technical criteria. Actually they do not use any optimisation algorithm, but try to find a good solution by a technical strategy. Branch exchange approach is the most common technical strategy which has been applied to distribution system optimisation problem [27–33]. The third category of approaches is metaheuristics which are very popular in solving distribution system optimisation problems and have shown satisfactory performance [34–37]. They are population-